UNITED STATES PATENT APPLICATION FOR:

LOW NO_x EMISSIONS, LOW NOISE BURNER ASSEMBLY AND METHOD FOR REDUCING THE NO_x CONTENT OF FURNACE FLUE GAS

INVENTOR(S):

Roger L. Poe
Jaiwant D. Jayakaran
Carol A. Schnepper

Attorney Docket No.: 506419-0070

Certificate of Mailing by "Express Mail" (37 C.F.R. 1.10)

Express Mail Label No.: EV 259628343 US

Date of Deposit: January 16, 2004

I hereby certify that this correspondence is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service on the date indicated above and is addressed to Mail Stop Patent Application, Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450

Signature: Lora Gurley

Printed Name: Lora Gurley

The Director is hereby authorized to charge any additional amount required, or credit any overpayment, to Deposit Account No. 19-4409.

LOW NO_x EMISSIONS, LOW NOISE BURNER ASSEMBLY AND METHOD FOR REDUCING THE NO_x CONTENT OF FURNACE FLUE GAS

REFERENCE TO RELATED APPLICATION

This application is a divisional of and claims priority pursuant to 35 U.S.C. § 120 from co-pending application serial no. 09/781,817, filed February 12, 2001, which application serial no. 09/781,817 in turn claims priority pursuant to 35 U.S.C. § 119(e) from provisional application serial number 60/184,615 filed February 24, 2000. The entireties of the disclosures of said prior applications serial nos. 09/781,817 and 60/184,615 are hereby specifically incorporated herein by this specific reference thereto.

BACKGROUND OF THE INVENTION

Field of the Invention

The invention relates to burners for large scale industrial applications. Such burners may be adapted for burning either gaseous fuels including natural gas or liquid fuels including fuel oil. In particular the invention relates to a low NO_x, low noise burner assembly which provides structure for recirculating flue gas directly from the inside of the fire box.

The State of the Prior Art

Environmental concerns today fuel a continuing search for burners which operate efficiently, economically, with a minimum amount of noise, and with a minimum amount of contamination, such as NO_x, in the flue gases. It has been determined previously that NO_x contamination may be reduced by recirculating flue gases back into the combustion zone. Various

methods have been envisioned and/or developed for accomplishing this recirculation, including motor driven fans and eductor devices. Generally speaking, conventional burners utilize only the motive force of combustion fuel to entrain furnace flue gas. This prior methodology is limiting in that the gas has high velocity but low mass resulting in low entrainment rates.

In addition, prior methodology has involved the use of burners including internal structural conduits for transporting the recirculated flue gases back to a place where the same may be reintroduced into the combustion zone. The structural requirements are extensive adding greatly to the cost to the overall installation. Accordingly there has been a need for structural features which will simplify the recirculation of flue gases.

SUMMARY OF THE INVENTION

The present invention provides a novel burner assembly which addresses the problems and shortcomings of the prior art. In particular, the invention provides a burner assembly that is of simple construction and facilitates the use of a simple and effective motive force for recirculating flue gases. In accordance with the concepts and principles of the present invention, it has been determined that the use of combustion air for entrainment of flue gases is much more efficient than the use of fuel gases for this purpose due to the tremendous difference in mass. The mass of combustion air is typically 10 to 12 times that of the combustion fuel gases. The invention also contemplates the simultaneous use of both combustion air and fuel gases to provide even greater motive forces for recirculating flue gases.

The burner assembly of the invention is adapted for being mounted on a wall or floor or roof of a furnace or fire box or the like which defines a combustion zone. In accordance with the concepts and principles of the invention, the burner assembly comprises a tile formation that has a portion which protrudes beyond the furnace wall and into the combustion zone. The tile formation presents an air passageway configured for conducting combustion air into the combustion zone and a recirculated flue gas (RFG) conduit that intercommunicates the air passageway and an area within the furnace adjacent the combustion zone when the burner assembly is mounted on the wall. In accordance with the invention, the RFG conduit is preferably located entirely within the protruding portion of the tile formation, whereby it is unnecessary to provide RFG conduits built into the furnace structure.

In a preferred form of the invention, for ease of assembly, the tile formation may include first and second tiles with the RFG conduit defined between the tiles. In this preferred form of the invention, the second tile may be mounted on a seating structure provided on the first tile. The first and second tiles may each have an annular body segment and the tiles may be arranged such that the annular body segment of the first tile is disposed in surrounding relationship to the combustion air passageway and the annular body segment of the second tile is disposed in surrounding relationship to at least a portion of the annular body segment of said first tile. Preferably, in accordance with the principles and concepts of the invention, the annular body segment of the first tile may have an outer surface and the annular body segment of the second tile may have an inner surface, and these surfaces may be arranged and positioned such that the RFG conduit is defined

between them. Ideally, the annular body segments may be arranged concentrically with the outer surface of the first tile spaced radially from the inner surface of the second tile such that the RFG conduit is essentially annular in shape.

In a particularly preferred mode of the invention, the second tile may have an annular edge which sits on a seating structure of the first tile. In this preferred mode, the seating structure may include at least one, preferably at least two and ideally four evenly circumferentially spaced shoulder members which extend radially outwardly from the outer surface of annular body segment of the first tile. In a most preferred embodiment of the invention, the shoulder members each include a notch configured for receiving and securing the annular edge of the second tile. Such structure facilitates the positioning of the tiles relative to one another and insures concentricity.

In a further preferred form of the invention, the burner assembly may include a fluid fuel burner nozzle disposed in the combustion air passageway. In this form of the invention, the fluid fuel burner nozzle may be adapted for delivering a gaseous fuel, preferably natural gas or a specially blended combustible mixture of gases, to the combustion zone. In accordance with the invention, the fluid fuel burner nozzle may preferably be adapted for accommodating pressurized gaseous fuels at various pressures within a given range. Alternatively, the fluid fuel burner nozzle may be adapted for delivering a liquid fuel, preferably a fuel oil, to the combustion zone.

The burner assembly of the invention may also comprise at least one fluid fuel burner nozzle disposed adjacent an entrance to the RFG conduit. In addition, or alternatively, the burner

assembly of the invention may include a fluid fuel burner nozzle disposed on an outer peripheral surface of the annular body segment of the second tile.

In further accordance with the concepts and principles of the invention, the burner assembly may be adapted for use in connection with a furnace having a firebox defining a combustion zone. This burner assembly may include a first annular tile defining a path for flow of combustion air and a second annular tile concentric with the first annular tile. The second annular tile may have an internal diameter which is larger than an external diameter of the first annular tile, and the second annular tile may be positioned in surrounding relationship relative to at least a portion of the first annular tile so that a ring-shaped RFG conduit is defined therebetween. In this form of the invention, the tiles may be adapted for placement in the combustion zone with the RFG conduit in direct fluid communication with flue gases in an area surrounding the combustion zone. The assembly may preferably be such that combustion air flowing along the flow path induces a flow of flue gas through the RFG conduit for entrainment by the flow of combustion air. Ideally the assembly may include a gas jet positioned adjacent an inlet to the RFG conduit providing a flow of gas for admixture with the flow of flue gas.

In still further accord with its concepts and principles, the invention provides an RFG inducing burner assembly. The assembly comprises a fuel nozzle arrangement that includes a nozzle positioned to direct a flow of fluid fuel along a flow path and into a combustion zone inside a furnace firebox. The assembly also includes a first tile structure having a central opening and which is located so that the central opening surrounds the nozzle and directs an annular flow of combustion

air past the nozzle in surrounding relationship to the fluid fuel flow path. The first tile structure desirably has an outer peripheral face that extends there around in surrounding relationship relative to the central opening. Also included is a second tile structure that has a central passageway. The second tile structure desirably is located so that its central passageway surrounds at least a portion of the first tile structure. The second tile structure may have an internal face which extends around its central passageway and such internal face may be disposed in spaced, facing relationship relative to the peripheral face of the first tile structure. An annular space is defined between the outer peripheral face of the first tile structure and the internal face of the second tile structure. Preferably, the tile structures are arranged such that the annular space therebetween is in direct intercommunication with an interior area within the firebox adjacent the combustion zone when the burner is operationally installed relative to the furnace. In accordance with the principles and concepts of the invention, the assembly of the tile structures may desirably be such that a flow of RFG from the interior area and through the annular space is induced by combustion air flowing through the opening of the first tile structure. In this regard it is to be noted that the assembly of the present invention may be used to augment flue gas recirculation in existing applications which employ a forced air design.

In another form the invention provides a low NO_x furnace that includes an RFG inducing burner assembly and a firebox providing a combustion zone. In this form of the invention, the burner assembly is operationally installed on a wall or roof or floor of the furnace to provide combustion air and a fluid fuel to the combustion zone. In accordance with the invention, the burner

assembly preferably comprises a fuel nozzle arrangement that includes a nozzle positioned to direct a flow of fluid fuel along a flow path and into the combustion zone within the firebox, a first tile structure that has a central opening, and a second tile structure that has a central passageway. The first tile structure may be located so that its central opening surrounds the nozzle and directs an annular flow of combustion air past the nozzle in surrounding relationship to the fluid fuel flow path. The first tile structure may also have an outer peripheral face which extends there around in surrounding relationship relative to the central opening thereof. The second tile structure may be located so that its central passageway surrounds at least a portion of the first tile structure. The second tile structure may also have an internal face which extends around the central passageway thereof. Desirably, in accordance with the concepts and principles of the invention, the internal face of the second tile structure is disposed in spaced, facing relationship relative to the peripheral face of the first tile structure, and the faces are preferably arranged so as to define an annular space therebetween. The tile structures further may be arranged such that the annular space therebetween is in direct intercommunication with an interior area of the firebox adjacent the combustion zone when the burner assembly is operationally mounted. Desirably, the arrangement of the tile structures is such that a flow of RFG from an area in the firebox adjacent the combustion zone and through the annular space is induced by combustion air flowing through the opening of the first tile structure. Again, the assembly of the present invention may be used to augment flue gas recirculation in existing applications which employ a forced air design.

In further accord with the concepts and principles of the invention, a method is provided for efficiently and effectively reducing the NO_x content of furnace flue gas produced by combusting air and a fluid fuel in a combustion zone of a furnace. In this form of the invention, the method involves the use of a burner assembly as described above for introducing RFG into the combustion zone.

In yet another aspect of the invention, a method is provided for efficiently and effectively reducing the NO_x content of furnace flue gas. This method may comprise providing a flow of a fluid fuel to a combustion zone in a firebox of the furnace, providing a flow of combustion air to the combustion zone, combusting the fluid fuel and the air in the combustion zone to thereby produce a flame, and using the motive force of the flow of combustion air to induce a flow of RFG directly from an area in the firebox adjacent the combustion zone and cause it to interact with the fluid fuel and the combustion air in the combustion zone. The formation and emission of NO_x in the furnace is thus reduced. Preferably, in accord with the concepts and principles of the invention, the combustion air flows along a longitudinal axis of an elongated burner assembly.

The invention also provides a method for operating a burner for a gas fired furnace having a fire box. In accordance with this aspect of the invention, the method preferably includes providing a flow of combustion air, providing a flow of combustion fuel, admixing the fuel and air, combusting the admixture of air and fuel in a combustion zone in the firebox, and inducing a flow of flue gas directly from an area in the fire box adjacent the combustion zone and into the admixture of combustion air and fluid fuel, and thus the flame, using the motive force of the flow of

combustion air. Desirably, the foregoing method may further include a step of using the motive force of the flow of combustion gas fuel to further induce a flow of flue gas from the area adjacent the combustion zone. Desirably, in this form of the invention also, the combustion air flows along a longitudinal axis of an elongated burner assembly.

One of the important features of the invention involves the use of primary air flowing axially through the burner assembly for entrainment of RFG directly from an area at the periphery of the combustion zone. The axial entrainment system of the invention enables the provision of a much more uniform and homogenous combustible gas mixture leaving the burner whereby typical stratification problems and resultant flame instability are alleviated. The advantages of the invention over prior art burner assemblies include, but are not limited to, (1) shorter flame length (0.5 to 1.1 foot per MMBtuh vs. 1.5 to 2 feet per MMBtuh); (2) larger turn down ratios (10 to 1 vs. 3 to 1); (3) much lower noise around burner; (4) tiles are not subjected to hot spots caused by burning jets piercing through the tile; (5) coking tendencies are reduced if not eliminated completely; (6) stability is greatly improved facilitating operation under substoichiometric conditions; (7) flame anchoring in an oxidizing zone is facilitated; (8) homogenous mixtures are provided leading to uniformity of flame patterns; (9) both prompt and thermal NO_x are lowered; (10) potentially both air and fuel gas may be used for flue gas entrainment; (11) flue gas entrainment is much more efficient; and (12) axial flame patterns reduce burner to burner interaction; (12) the assembly of the invention may be coupled with RFG in forced air applications; (13) the assembly of the invention is even more efficient when used in connection with a forced air design.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 is a side elevational view of a burner assembly which embodies the concepts and principles of the present invention;

FIGURE 2 is a plan view looking upwardly at the lower end of the burner as it is positioned in **FIG. 1**;

FIGURE 3 is an enlarged plan view looking downwardly at the upper end of the burner as it is positioned in **FIG. 1**;

FIGURE 4 is an enlarged detail view illustrating the portion of the burner assembly within the **Circle 4.** of **FIG. 2**;

FIGURE 5 is an enlarged detail view illustrating the portion of the burner assembly within the **Circle 5.** of **FIG. 3**;

FIGURE 6 is an enlarged detail view illustrating the portion of the burner assembly within the **Circle 6.** of **FIG. 3**;

FIGURE 7 is an enlarged view, partly in cross-section illustrating the tile formation of the burner assembly of **FIG. 1**;

FIGURE 8 is a top plan view of the lower (upstream) tile of the tile formation of **FIG. 7;**

FIGURE 9 is a side elevational view of the lower tile of **FIG. 7;**

FIGURE 10 is a side elevational view, partly in cross-section, illustrating the upper (downstream) tile of the tile formation of **FIG. 7;** and

FIGURES 11 through **16** are side elevational schematic views illustrating several alternative embodiments of the burner assembly of the invention.

FIGURE 17 is a side elevational view, partly in cross-section, illustrating an alternative form of a burner assembly which embodies the concepts and principles of the present invention;

FIGURE 18 is a top plan view of the burner of **FIG. 17**;

FIGURE 19 is a cross sectional view taken substantially along the line 19-19 of **FIG. 17**;

FIGURE 20 is a cross sectional view taken substantially along the line 20-20 of **FIG. 18**;

FIGURE 21 is a cross sectional view taken substantially along the line 21-21 of **FIG. 18**;

FIGURE 22 is a side elevational view, partly in cross-section, illustrating yet another alternative form of a burner assembly which embodies the concepts and principles of the present invention; and

FIGURE 23 top plan view of which is similar to **FIG. 18** but illustrates an alternative embodiment of a burner embodying the concepts and principles of the invention which is rectangular in shape rather than circular.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

A burner assembly which embodies the concepts and principles of the invention is illustrated in Fig. 1 where it is identified broadly by the reference numeral 20. The assembly 20 is particularly adapted for being mounted as shown on a wall 22 of a fire box of a furnace or the like. Wall 22 defines a combustion zone 24 disposed generally at and around the upper end 26 of assembly 20 as the latter is depicted in Fig. 1. It will be appreciated by those skilled in the burner art, however, that the orientation of the assembly 20 is not necessarily critical and the same may be used in any one of a variety of positions such that the flame generated thereby is projected upwardly, downwardly, horizontally or at an angle relative to horizontal. Accordingly, defining end 26 as an upper end is done only for convenience of reference. Moreover, it will be appreciated that the principles and concepts of the invention are not limited to use with round burner tiles. In this regard, the principles and concepts of the invention may also be applied to burners having rectangular shaped burner tiles, flat flame burners and burners with an axisymetric design.

Burner assembly 20 includes the conventional accessories needed for operation, including an air inlet 28 adapted for connection to a source of air for combustion, an air box 30, and a manifold system 32 adapted for connection to a source of fuel and distributing the same to respective individual burner nozzles of the burner assembly. These devices are conventional and well known to those skilled in the burner art. Assembly 20 may include a flange 33 for attaching the same to wall 22 as can be seen in Figs. 1 and 7. The flange 33 may be secured to the wall 22 using a conventional nut and bolt (or stud) arrangement (see Fig. 4).

Burner assembly 20 is particularly adapted for inducing a flow of flue gases from an area 34 adjacent combustion zone 24 and recirculating the same for diluting the air and fuel mixture combusting in the combustion zone 24. These recirculated flue gases are often referred to as RFG (or FGR), and it is a well known phenomena that when RFG is mixed in with the combusting air and fuel in the combustion zone, NO_x emissions are reduced.

In accordance with the invention, assembly 20 includes a tile formation 36 having a portion 38 which protrudes beyond wall 22 and into the combustion zone 24 as shown in Fig. 1. That is to say, portion 38 of tile formation 36 protrudes into and is positioned essentially within combustion zone 24. Formation 36 includes a first, lower, upstream, inner tile structure 40 and a second, upper, downstream outer tile structure 42. As can particularly be seen viewing Fig. 7, tile 42 is mounted on a seating structure 44 of tile 40.

As can best be seen viewing Figs. 7, 8 and 9, in the preferred embodiment of the invention depicted in the drawings, tile 40 includes a generally annular body segment 46 which surrounds a central opening 48, a base 50, and a plurality of shoulder members 52 which preferably are essentially identical and evenly spaced about the periphery of body segment 46. As shown in the drawings, the depicted assembly includes four of the shoulder members 52; however, those skilled in the art would recognize that the assembly could just as well be designed to employ only three shoulder members 52. As can be seen, the shoulder members 52 extend radially outwardly from the outer peripheral surface 54 of annular body segment 46, and together, they provide the seating structure 44 for tile 42 mentioned above. To this end, the shoulder members 52 are each provided

with a notch 56 which is configured to receive and secure an annular edge portion 58 of tile 42. That is to say, when the tiles 40 and 42 are assembled so as to present the tile formation 36, the edge portion 58 of tile 42 sits on a generally horizontal ledge 60 which is part of the corresponding notch 56. The manner in which the edge portion 58 is received and secured by the notches 56 is best illustrated in Fig. 7. As can be seen, surface 54 essentially extends around tile 40 and surrounds opening 48. The tiles 40, 42 of the tile formation 36 may be connected together using well known conventional attachment devices. If the tile formation 36 is mounted on a bottom wall of a furnace, tile 42 may simply rest on the seating structure 44. On the other hand, if the tile formation 36 is mounted in some other position, tile 42 may be attached to tile 40 using elongated studs that are cast into tile 42 at positions that correspond to the locations of the notches 56. Stud receiving holes may then be provided to extend downwardly through shoulder members 52 from the notches 56 to the flange 33 where nuts may be used to secure the tiles 40, 42 to flange 33 via the elongated studs.

With reference to Figs. 3, 7 and 10, in the preferred embodiment of the invention depicted in the drawings, tile 42 has an annular body segment 62 that surrounds a central opening 64 thereof. The internal diameter of tile 42 is greater than the external diameter of tile 40. Thus, as can particularly be seen in Fig. 7, when tile 42 is mounted on tile 40, annular body segment 62 of tile 42 surrounds at least a portion of annular body segment 46 of tile 40. In particular, the lower edge portion 58 of annular body segment 62 surrounds the upper frusto-conical portion 68 of annular body segment 46. Thus, it can be seen that the annular body segments 46 and 62 are arranged concentrically with the outer annular surface 70 of the upper frusto-conical portion 68 of tile 40

spaced radially inwardly from the inner annular surface 72 of lower edge portion 58 of tile 42. Manifestly, therefore, inner surface or face 72 of tile 42 is disposed in a surrounding relationship relative to frusto-conical portion 68 of tile 40.

When tile 42 is seated on tile 40 in an operational position as shown in Figs. 3 and 7, it can be seen that central opening 48 of tile 40 together with central opening 64 of tile 42 present a passageway 74 defining a path 76 along which combustion air from air box 30 is conducted into combustion zone 24. As can be seen viewing Figs. 3 and 7, passageway 74 is surrounded by the respective annular body segments 46 and 62 of tiles 40 and 42 as well as by annular face 72 (not seen in Fig. 3) which extends there around.

As mentioned above, outer annular surface 70 of the upper frusto-conical portion 68 of tile 40 is spaced radially inwardly from the inner annular surface 72 of lower edge portion 58 of tile 42. Thus, surfaces 70 and 72 are disposed in spaced, facing relationship relative to one another. The annular space 78 between surfaces 70 and 72 (see Fig. 3) provides an annular or ring-shaped RFG conduit 80 which intercommunicates air passageway 74 with the area 34 which is adjacent combustion zone 24. Thus, RFG conduit 80, which is defined between upper and lower tiles 40, 42, is in direct communication with flue gases in the area 34 surrounding combustion zone 24 so that combustion air flowing along path 76 is able to induce a flow of flue gas from area 34 and through conduit 80 for entrainment by the combustion air and dilution and cooling of the gases combusting in combustion zone 24 to thereby reduce the production of NO_x. That is to say, the arrangement of the tiles 40, 42 is such that a flow of RFG from area 34 and through annular space 78 is induced by

the action of the combustion air flowing along passageway 74 and through the openings 48 and 64. The combustion air flowing past the downstream end 81 of conduit 80 creates a motive force for inducing a flow of RFG through conduit 80. Thus, the arrangement of the tiles provides an action much like an eductor or an ejector. That is to say, the mass of combustion air flowing in the direction of arrow 76 entrains RFG directly from the area 34 in the interior of the firebox which surrounds the tile assembly 20 of the invention. The RFG flows in the direction of the arrows 85 from the area 34, through the ring-shaped conduit 80 and past end 81 of the latter where it joins and is entrained by the combustion air flowing along path 76. The mass of combustion air flowing in the direction of the arrow 76 thus provides the motive force for entraining the flue gases directly from the area 34 along the path of the arrows 85 and delivering it to the outlet end 83 of gas nozzle 82 where it is diffused and admixed with the combustion mixture, thus slowing the rate of reaction of the fuel with oxygen from the combustion air.

In accordance with the invention, the downstream tile 42 is located around the upstream tile 40 so as to form the ring-shaped conduit 80 which is open to the furnace gases in the interior of the furnace. These furnace gases are able to interact with the air flowing along path 76 through the center of tile 42 to create a combined flow leaving the tile system of approximately 118% of inlet air quantity (volume). This added furnace gas is swept around the flame in combustion zone 24 slowing the diffusion of air into the main flame in a very uniform and homogenous manner.

At this point it is to be noted that although tile 40 is shown as having four shoulder members 52, the number actually desired and/or required for a given application may vary depending upon, for example, such things as the overall dimensions of the tiles, the orientation of the assembly, the weight of tile 42 and/or the flow areas required for passageway 74 and conduit 80.

In the preferred embodiment of the invention illustrated in Figs. 1 through 10 of the drawings, burner assembly 20 may include primary, secondary and tertiary fluid fuel burner nozzles. Primary nozzle 82, which is illustrated particularly in Figs. 3 and 7, is surrounded by tiles 40 and 42 and is generally centrally located in passageway 74, whereby an annular flow of combustion air is directed past nozzle 82 in central opening 64. Accordingly, the combustion air initially flows in a surrounding relationship relative to the flow of fuel emanating from nozzle 82. Although the nozzle 82 as shown is particularly adapted for delivering a gaseous fuel to the combustion zone, it is to be understood that in accordance with the concepts and principles of the invention, nozzle 82 may be adapted for delivering either a liquid fuel, for example a fuel oil, or a gaseous fuel, for example natural gas, along a path which is generally parallel to path 76 to the combustion zone.

In the preferred embodiment of the invention, burner assembly 20 may also include a plurality, preferably four (4), secondary burner nozzles or gas jets 84. These nozzles 84, which are particularly illustrated in Figs. 1, 3, 5 and 7, are disposed adjacent the inlet 86 of RFG conduit 80 whereby fuel gas is admixed with RFG. In addition, the gas emanating from nozzles 84 provides a motive force for further inducing a flow of RFG from area 34. As will be appreciated by those skilled in the burner art, there is nothing critical about the number of nozzles 84, and for any given

application, the number thereof may vary from zero (0) to eight (8) or more. However, when the assembly includes a multiplicity of such secondary nozzles, the same should be spaced evenly about the outer periphery of annular tile segment 46 as shown.

Burner assembly 20 may also include a plurality, preferably four (4), tertiary burner nozzles or gas jets 88. These nozzles 88, which are particularly illustrated in Figs. 1, 3, 6 and 7, may preferably be mounted in respective channels 90 provided in the outer peripheral surface 92 of annular tile segment 62. Desirably, the shoulder members 52 may be provided with end faces 94 which provide support for the tubes 96 supplying fuel to nozzles 88. As will once again be appreciated by those skilled in the burner art, there is nothing critical about the number of nozzles 88, and for any given application, the number thereof may vary from zero (0) to eight (8) or more. However, when the assembly includes a multiplicity of such tertiary nozzles, the same should be spaced evenly about the outer periphery 92 of annular tile segment 62 as shown.

SPECIFIC EXAMPLE

A specific example of the operation of a furnace using the embodiment of the present invention described above and shown in the FIGS. 1 through 10 of the drawings is as follows:

Burner is fired at 8.0 MMBtuh. Excess air is 15%. Furnace temperature is 1500 °F. Burner differential pressure is 0.3 inches of H_2O. Burner damper is fully opened. Combustible gas is 100% natural gas. Single central fuel nozzle configuration. The results obtained in the flue gas include 3% measured oxygen, 0 ppm measured CO and approximately 20 to 35 ppm measured NO_x.

In the foregoing description and specific example, the fuel has been described principally as being fuel gas or natural gas. It is to be noted in this regard, that the burner of the invention may also be used effectively for reducing NO_x emissions when burning other fluid fuels, such as, for example, normally liquid fuels including fuel oil or other gas blended fuels. It is also to be noted that existing installations may be retrofitted so as to use the principles and concepts of the present application.

As illustrated and described above, the burner assembly 20 of the invention includes primary, secondary and tertiary burners. Alternative embodiments are illustrated schematically in Figs. 11 through16. In each case, the schematically shown tile formation including concentric tiles may be essentially the same as the tiles 40 and 42 described above. As shown in Fig. 11, the illustrated burner assembly may include only a single centrally located primary burner nozzle. As shown in Fig. 12, the illustrated burner assembly may include two or more burner nozzles located adjacent the outer peripheral surface of the upstream tile near the inlet to the RFG induction conduit. As shown in Fig. 13, the illustrated burner assembly may include two or more burner nozzles located on the internal surface of the central opening in the upstream tile adjacent the RFG induction conduit. As shown in Fig. 14, the illustrated burner assembly may include a centrally located primary burner nozzle and two or more burner nozzles located on the outer peripheral surface of the downstream tile. As shown in Fig. 15, the burner assembly may include a single centrally located primary burner nozzle that is equipped with a premixer and conventional swirler mechanism. As shown in Fig. 16. the burner assembly may be arranged essentially as described above in connection

with Figs. 1 through 10, except in this case the central burner nozzle is particularly adapted for delivering a liquid fuel. In each case, the flow of RFG from area 34 and through conduit 80 is induced by combustion air flowing along path 76 past end 81 of the conduit.

An alternative form of a burner arrangement which embodies the concepts and principles of the invention is illustrated in FIGS. 17 through 21 where the arrangement is identified broadly by the reference numeral 120. The burner arrangement 120 is similar in configuration to the burner arrangement 20 except for the manner in which the upper tile 142 sits on the lower tile 140. This in turn changes the configuration of the annular space 178 defined between the tiles 140 and 142.

With reference to FIGS. 17 through 21, it can be seen that the lower tile 140 includes a plurality of shoulder members 152 which project radially outwardly from the outer peripheral surface 154 of annular body segment 146. Together the upper surfaces 153 of the members 152 provide a seating structure 144 for tile 142. To this end, upper tile 142 is provided with a plurality of downwardly projecting feet 159. In accordance with the invention, the number of feet 159 on upper tile 142 corresponds with the number of members 152 on lower tile 140, and as can be seen, the feet 159 are positioned to sit on the upper surfaces 153 when the tiles are assembled. With this arrangement, the lower edge portion 158 of the upper tile 142 is spaced vertically from the upper edge portion 161 of the lower tile 140. Such spacing provides a configuration for the annular space 178 which is different than the configuration of the annular space 78 of burner assembly 20. This spacing also changes the configuration of the path 185 provided for the flow of flue gas from the

interior of the furnace and into the central passageway 174 within the tiles 140, 142. Such flow, of course, is induced by the flow of combustion air along the path 176 as well as by the flow of fuel gas from nozzles 184. Tile 142 may be attached to tile 140 using conventional means, for example, studs extending downwardly from feet 159 through stud receiving holes extending through the shoulder members 152.

With reference to FIG. 19, it can be seen that the channels 190 are offset angularly relative to the shoulder members 152, whereas, in the burner arrangement 20, the channels 90 are not offset angularly relative to the shoulder members 52. In accordance with the concepts and principles of the invention, the channels 190 are preferably offset 45° relative to the shoulder members 152. This angular offset places the nozzles 184 in positions where there is a minimum of structure to hinder the flow of fuel from the nozzles 184 and into the annular space 178.

Another alternative form of a burner arrangement which embodies the concepts and principles of the invention is illustrated in FIG. 22 where the arrangement is identified broadly by the reference numeral 220. The burner arrangement 220 is essentially the same as the burner arrangement 120 except for the placement of the burner nozzles 284 and the radial dimension of the shoulder members 252. The arrangement of FIG. 22 facilitates the employment of a burner which may be smaller in diameter than the burner arrangement 120.

Yet another alternative form of a burner arrangement which embodies the concepts and principles of the invention is illustrated in Fig. 23, where the arrangement is identified broadly by the reference numeral 320. The burner arrangement 320 is essentially the same as the

arrangement 120 described above except for the general shape thereof which is rectangular rather than circular. Components of arrangement 320 which correspond with elements of arrangement 120 are designated using reference numerals in the 300 series.

The burner arrangements of the present invention achieve low NO_x emissions, low noise, air entrainment of RFG, prompt NO_x alleviation, simplicity of construction, short flame profile, high turndown ratios, high stability and low CO emissions. Flow of RFG is induced without mechanical devices such as blowers by using the combustion air as a motive force for entrainment of RFG instead of fuel gas. In addition, the arrangement is such that the secondary gas tips are located behind a burner tile so that jet noise is shielded from the outside of the burner. Moreover, diffusion of RFG directly from the interior of the furnace directly into the gas jet prior to combustion results in reduction of prompt NO_x. The arrangement is simple resulting in low manufacturing costs while providing ease of operation.

An important feature of the invention is the provision of a non-powered means of supplying flue gas to a burner to reduce NO_x emissions and enhance mixing of combustion air, fuel gas and RFG to facilitate homogeneity of the mixture. The burner arrangement is based at least in part upon the important concept of using the mass of the axially flowing combustion air to entrain RFG from the furnace and mix it with the entering fuel gas in sufficient amounts while ensuring that the mixture remains combustible. As mentioned previously, the invention also contemplates the use of both the mass of the axially flowing combustion air and the mass of the fuel provided through gas jets to entrain RFG from the furnace and mix it with the entering fuel.

The impedance of combustion caused by the flue gas entering the nozzle arrangement directly in accordance with the invention lowers the flame temperature, thus inhibiting the formation and emission of NO_x. Prior to the design of the invention, only small amounts of flue gas were entrained by individual gas jets inspirating flue gases into the tile block. The old design proved to be fairly inefficient with the stratification of flue gases causing long flames and burner instability. The present invention utilizes the energy of the large mass of flowing combustion air leading to a greater mass of flue gas entrainment and consequent more efficient mixing with the gas jet and flame. An important note here is that the air induced flue gas entrainment is performed in the furnace space and the flue gases are not required to go back into the burner body as with some previous burner arrangements.

In the simplest configuration of the burner the flame is ignited and stabilized in an oxidizing zone within the primary tile. The flame envelope is quickly extended into the flue gas rich secondary zone where NO_x formation and emission is inhibited. The flame envelope never loses stability as it enters the secondary flue gas diluted zone as it is firmly anchored and defined in the primary (oxidizing) zone contained in the primary tile section. This rapid diffusion and rapid quenching without instability conserves short flame lengths and large turndown ratios. Flame lengths are typically 1.1 feet or less per million BTUs of firing rate (fuel dependent) and turndown rates typical of natural draft low NO_x burners on the order of 10 to 1 may easily be achieved. CO emissions are typically zero, but are somewhat dependent upon furnace temperature.

Configurations of the burner of the invention other than as shown in the drawings include staged fuel with either a gas gun being utilized or with primary risers inserted into the ring-shaped conduit for additional NO_x abatement. When an annular primary tile is utilized as shown in the drawings, the riser is shielded from the outside of the burner by the primary tile greatly reducing the jet noise emitted by the burner to the exterior. The primary risers are set low enough in the ring-shaped conduit so that the gas jet has sufficient time to entrain pure flue gas prior to entering the oxidizing zone. This premixing of flue gas with the combustion gas lowers the speed at which the combustion gas can react thus additionally reducing the formation of NO_x. Once the gas jet starts to burn it does so in an atmosphere rich with flue gas which is constantly being entrained by the combustion air. The overall effect is ultra low NO_x as both prompt and thermal NO_x are greatly reduced. The overall simplicity of the burner combined with the stability achieved in the oxidizing zone make the burner arrangements of the invention an important advance relative to existing technologies.